# Effect of Internal Waves on Acoustic Interference Structure

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## LONG-TERM GOALS

Our long-term goal is to determine the extent to which a single scalar parameter can characterize observed striations in acoustic intensity patterns.

## OBJECTIVES

In the second edition of *Fundamentals of Ocean Acoustics,* Brekhovskikh and Lysanov [1991] introduced the concept of waveguide invariance to a larger audience. They showed how contour plots of acoustic intensity, mapped in range and frequency, would exhibit striations. They defined a parameter "beta" as a simple function of range, frequency and the slope of the striations, and claimed that this parameter was invariant. They considered a deep-water ocean waveguide problem with a sound speed duct and found $\beta$= -3. In shallow water, they assumed an isovelocity water column and found $\beta$= +1.

The objectives of the present work are to estimate beta for more realistic scenarios and to determine the extent to which it is truly an invariant. In particular, the effects of time-varying shallow water internal waves are studied.

## APPROACH

Beginning with the article by Chuprov [1982], a number of Russian papers examine aspects of the waveguide invariant problem. The more theoretical of these studies relied on analytical techniques. Perturbation theory, adiabatic modes, the WKB approximation and other simplifications were necessary to get closed form solutions.

In the present work, numerical simulations are used to evaluate the concept of waveguide invariance. Realizations of time-evolving shallow water internal waves are synthesized. Acoustic propagation through the resulting range-dependent environment is simulated using the parabolic equation. Both random background internal waves and more event-like solitary waves are considered. Beta is estimated from images of intensity and tracked as the internal wave field evolves. Other simulation parameters are also varied. These parameters include the bottom attenuation as well as the range and depth of the receiver.

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## WORK COMPLETED

A version of the wide-angle parabolic equation routine FEPE [Collins, 1988] was modified to generate images of acoustic intensity plotted versus range and frequency. The code used as input the results from a three-dimensional ocean internal wave simulator [Winters and D'Asaro, 1997]. A new method for quantifying the "beta content" of the intensity images was developed.

## RESULTS

For a shallow-water environment characterized by a downward refracting sound speed profile, the numerical value for beta is a function of receiver depth. Figure 1 illustrates the result. Shown are two transmission loss maps in the range-frequency plane. In Fig. 1(a), the receiver is shallow and above the thermocline. In Fig. 1(b), the receiver is deep and below the thermocline. Superimposed on the figures are lines corresponding to $\beta=1$, the canonical value predicted by Brekhovskikh and Lysanov, and $\beta=2$. Both plots show striations, ridges of high intensity. The striations for the shallow receiver are consistent with the canonical value, but beta appears to be closer to 1.5 for the deep receiver. The results can be explained using a modal analysis [Rouseff, 2000].

The primary question addressed was how shallow water internal waves would affect beta. To answer this, it was necessary to find a technique for estimating beta from images such as in Fig. 1. An image processing method was developed that treats the intensity as a function of beta; consequently, it is the "beta content" of images that is calculated. This converts two-dimensional images into line plots of image energy versus beta. The mathematical details are in Rouseff [2000].

The simulation leading to Fig. 1(b) was modified by including background internal waves. The properties of the simulated internal waves were based observations in a recent experiment [Williams, et al., 2000]. Figure 2(a) shows the beta content of the images evolving over three hours. Note that while the details of the curves change, there is a persistent maximum near $\beta = 1.5$, the value for the range-independent case, Fig. 1(b). In a practical sense, the "invariant parameter" is indeed invariant to the fluctuations induced by internal waves for this case. The intermittent local maximum near $\beta = 1$ is due to energy in the higher order, surface interacting modes.

Additional calculations were performed using the same realizations of the internal wave field, but varying other parameters. Increasing the bottom loss smeared the relatively sharp maximum near $\beta=1.5$ observed in Fig. 2(a). Increasing the range to the receiver tended to sharpen the maximum, but also appeared to shift it location to slightly larger values of beta.

In addition to random background internal waves, discrete internal waves ("solibores") are also often present in shallow water. To make an initial attempt at simulating their effects on beta, the Preisig and Duda model [1997] of a solitary wave packet was employed. Initially, the packet was placed midway between the acoustic source and the receiver. The packet was then moved toward the acoustic source at 0.6 m/s, a speed consistent with observations in the SWARM 95 experiment. Range-frequency images of acoustic intensity were generated in one-minute increments. The beta content of each image was calculated, and the result is shown in Fig. 2(b). Even with one-minute sampling, there is considerable variability from curve to curve. Individual plots exhibit a range of values for beta. There is no obvious persistent maximum near $\beta=1.5$. Unless a more sophisticated processing scheme can be developed, the solitary waves appear to destroy the invariance of the intensity striations for the parameters used in this simulation.

## IMPACT/APPLICATIONS

The concept of a waveguide invariant has enormous appeal. When valid, it says that the interference structure of the acoustic field can be largely characterized by a single scalar parameter. This parameter accounts for the dispersion properties of what could be a very complicated propagation environment. Beta constitutes a robust observable; while the details of the intensity striation pattern may change in time, a waveguide invariant should remain constant. The waveguide invariant has been proposed as a method for source localization [Brekhovskikh and Lysanov, 1991]. More recently, it has been proposed as a method for environmental characterization [Dozier, Wilson and Fabre; presented to EAST Peer Review, 2000].

## RELATED PROJECTS

This work leveraged results from other ONR supported projects. These projects include ones that developed the internal wave model [Williams et al., 2000], the internal wave simulator [Winters and D'Asaro, 1997], and the acoustic model [Rouseff, presented elsewhere in this document].

In recent years, other Western investigators have begun to evaluate the waveguide invariant concept [Kuperman et al., 1999; Thode, 2000]. It was used to move the focal range in a phase conjugation experiment [Hodgkiss et al., 1999]. The theory was extended to environments varying in azimuth and used in the analysis of single receiver spectrograms [D'Spain and Kuperman, 1999].

## REFERENCES

L. M. Brekhovskikh and Y. P. Lysanov, *Fundamentals of Ocean Acoustics,* 2nd ed. (Springer-Verlag, New York, 1991), pp. 140-145.

S. D. Chuprov, "Interference structure of a sound field in a layered ocean," in *Ocean Acoustics. Current State*, edited by L. M. Brekhovskikh and I. B. Andreevoi (Nauka, Moscos, 1982), pp. 71-91.

M. Collins, "FEPE user's guide," Naval Ocean Research and Development Activity NORDA Tech. Note 365 (Stennis Space Center, MS, 1988).

L. B. Dozier, J. H. Wilson and J. Fabre, "Solving the inverse beta problem (IBP) using surface ships of opportunity." Presented to EAST Peer Review, Austin, TX (2000).

G. L. D'Spain and W. A. Kuperman, "Application of waveguide invariants to analysis of spectrograms from shallow water environments that vary in range and azimuth, J. Acoust. Soc. Am. **106**, 2454-2468 (1999).

W. S. Hodgkiss, H. C. Song, W. A. Kuperman, T. Akal, C. Ferla, and D. R. Jackson,"A long-range and variable focus phase-conjugation experiment in shallow water," J. Acoust. Soc. Am. **105**, 1597-1604 (1999).

W. A. Kuperman, G. L. D'Spain, H. C. Song and A. M. Thode, "Application of the waveguide invariant approach," J. Acoust. Soc. Am. **105**, 983 (1999).

J. C. Preisig and T. F. Duda, "Coupled acoustic mode propagation through continental-shelf internal solitary waves," IEEE J. Oceanic Eng. **22**, 256-269 (1997).

A. Thode, "Source ranging with minimal environmental information using the virtual receiver and waveguide invariant concepts," J. Acoust. Soc. Am. **107**, 2867 (2000).

K. L. Williams, F. S. Henyey, D. Rouseff, S. A. Reynolds and T. E. Ewart, "Internal wave effects on high frequency acoustic propagation to horizontal arrays: Experiment and implications to imaging," to appear in IEEE J. Oceanic Eng., (2000).

K. B. Winters and E. D'Asaro, "Direct simulation of internal wave energy transfer," J. Phys. Oceanog. **27**, 270-280 (1997).

**PUBLICATIONS**

D. Rouseff, "On the invariance of intensity striation patterns: Effect of shallow water internal waves," submitted to *J. Acoust. Soc. Am.*, (2000).

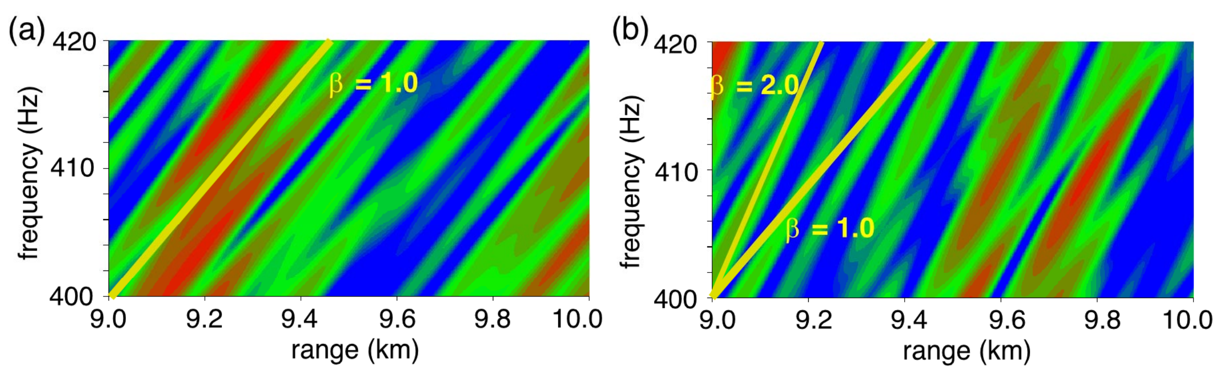


***Figure 1. Transmission loss in range-frequency plane. Color scale spans 16 dB dynamic range. Range is distance from source at constant depth. Lines superimposed on images correspond to candidate values for the invariant parameter beta. Range-independent water column described by sound speed profile that is nearly isovelocity down to about 12 m followed by a fairly steep gradient. The gradient gradually lessens, and below about 45 m the water is nearly isovelocity down to the bottom at 70 m. (a) Receiver depth 10 m. (b) Receiver depth 50 m.***

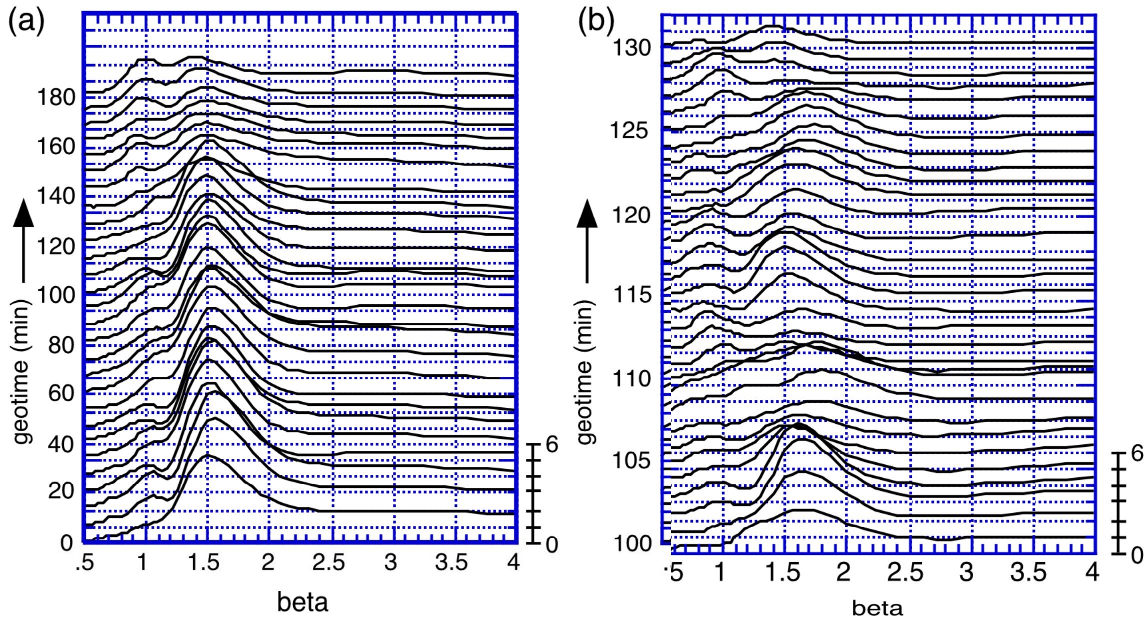


*Figure 2. Effect of internal waves on the waveguide invariant. The "beta content" of range-frequency images of intensity are plotted as the internal wave field evolves. (a) Background internal waves. Persistent maximum near $\beta$=1.5 is observed. (b) Solitary internal wave packet. Packet moves toward acoustic source at 0.6 m/s. See text and Rouseff [2000] for details of simulations.*